DOT/FAA/AM-03/6

Office of Aerospace Medicine
Washington, DC 20591

Natural Sunlight and Its Association to Aviation Accidents: Frequency and Prevention

Van B. Nakagawara
Kathryn J. Wood
Ron W. Montgomery
Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

May 2003

Final Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AM-03/6		

4. Title and Subtitle	5. Report Date
Natural Sunlight and Its Association to Aviation Accidents: Frequency and Prevention.	May 2003
	6. Performing Organization Code

7. Author(s)	8. Performing Organization Report No.
Nakagawara VB, Wood KJ, Montgomery RW	

9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125	11. Contract or Grant No.

12. Sponsoring Agency name and Address	13. Type of Report and Period Covered
Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave, S.W. Washington, DC 20591	14. Sponsoring Agency Code

15. Supplemental Notes

16. Abstract

INTRODUCTION. Glare is a temporary visual sensation produced by luminance (brightness) within the visual field that is significantly greater than that to which the eyes are adapted. Aviators may be subjected to intense glare from natural and artificial light sources that can result in temporary visual impairment, greatly increasing the risk of accidents. The purpose of this study was to investigate the relationship between visual impairment from natural sunlight and aviation accidents. **METHODS.** The National Transportation Safety Board Aviation Accident/Incident Database was queried for the period 1/1/1988 to 12/31/1998 for terms related to glare including sun, glare, vision, blinded, and reflections. All reports annotated with one or more of these terms were reviewed to determine whether glare from natural sunlight was considered a direct or contributing factor in the aviation accident. Accidents that did not involve the pilot-in-command of an air transport or general aviation aircraft were omitted. **RESULTS.** For the study period, there were 130 accidents in which glare from natural sunlight was found to be a contributing factor. The majority of the events occurred during clear weather and atmospheric conditions (85%), and were associated with approach/landing and takeoff/departure phases of flight (55%). **CONCLUSIONS.** Exposure to glare from natural sunlight has contributed to aviation accidents, primarily under optimal visual conditions. The majority of accidents occurred during flight maneuvers at low altitude in airspace congested with other aircraft or obstacles, such as trees, power lines, utility poles, and terrain. Preventative techniques are presented that may protect a pilot's visual performance against the debilitating effects of glare from the sun.

17. Key Words	18. Distribution Statement
Aviation Vision; Accident Risk; Glare; Visual Impairment; Afterimage; Flashblindness	Document is available to the public through the National Technical Information Service; Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	8	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Natural Sunlight and Its Association to Aviation Accidents: Frequency and Prevention

INTRODUCTION

Glare is a temporary sensation produced by luminance (brightness) within the visual field that is significantly greater than that to which the eyes are adapted (1) and is not associated with biological damage. The effects on vision from glare only last as long as the light source is present within the individual's field of vision. Glare has been classified as either "discomfort" or "disability" (2,3). Discomfort glare is the subjective response of annoyance caused by a light source without any measurable effect on visual performance. Disability glare is a loss of visual performance by the apparent scattering of light within the eye (1). In some instances, after exposure to a bright light, flashblindness (a visual interference effect that persists even after the source of illumination has been removed) or afterimage (a transient image left in the visual field after exposure to a bright light) may occur. These effects can result in prolonged visual impairment and be extremely hazardous to individuals that require optimum vision, such as a pilot in flight.

In normal young eyes, approximately 10 to 20% of the light incident on the corneal stroma is scattered, causing a reduction in the contrast of the retinal image (4). This reduction in retinal image quality can be particularly debilitating when viewing objects of low contrast and while looking through a compromised optical media (e.g., scratched or dirty windscreens, eyeglasses, and contact lenses) or certain atmospheric conditions (e.g., haze, fog, and mist). Additionally, individuals with lightly pigmented eye color may be less tolerant of bright light than those with darker pigmentation (5,6). This may be due to lighter pigmentation of the retinal epithelium, which absorbs less of the scattered light rays and results in visual noise (7).

Some abnormal ophthalmic conditions can increase glare sensitivity. Cataract (opacification of the eye's crystalline lens) is a source of intraocular scattering that results in "ghost images" (halos around lights) or a "dazzling" sensation, which can be caused by bright car headlights or intense sunlight (8,9,10,11). Other ophthalmic conditions that can result in discomfort or disability glare include age-related macular degeneration (12,13,14), pterygium (15), corneal scarring, corneal edema from contact lens wear (16,17), aphakia (18,19), intraocular lens implants (20,21,22), lens capsule opacification after cataract surgery (23,24,25), radial keratotomy (26,27), and laser refractive surgery (28,29,30,31).

Certain medications and drugs can affect an individual's ability to tolerate illumination by high-intensity light sources. Photosensitizing medications include: antibiotics (tetracycline, sulfonamide) (32), oral contraceptives (estrogen, progesterones) (33), or acne medications (Accutane™) (34). Additionally, alcohol use can result in an increase in glare recovery time. Relatively low doses of alcohol can produce a significant increase in glare recovery time, which may last for several hours after ingestion (35). Marijuana significantly delays the time course of glare recovery after intense light exposure (36) and may have additive effects when used with alcohol or other drugs that can further reduce glare tolerance and increase recovery time.

Pilots are exposed to various meteorological conditions while in-flight that may increase glare and limit visibility and contrast. For example, aviators are often subjected to direct and indirect sunlight, which can act as an intense source of glare. Furthermore, airmen flying at high altitude may be exposed to darkened skies above and bright reflected light from the clouds beneath. The contours of the human face serve to protect the eyes from bright light coming from above, but not from below (37). At 10,000 feet above ground, an aviator is exposed to approximately 11,800 foot-candles, while at sea level the exposure is approximately 10,000 foot-candles (38). Finally, an aviator may be temporarily visually disabled from sunlight scattering off dirty or damaged windscreens when flying out from behind the shadow of a mountain or flying out of cloud cover into a brightly-lit environment.

Harsh environmental lighting conditions may seriously compromise an aviator's ability to "see-and-avoid" other aircraft in the adjacent airspace or complete critical flight operations (landings, takeoffs). Life-threatening situations may develop in an instant if a pilot is visually impaired due to glare at a critical moment. At lower altitudes, where these operations are often executed, there is less time to react, and the risk of an aviation accident increases dramatically.

The FAA's Vision Research Team has an ongoing research program that investigates issues involving lasers

and other high-intensity light sources and their effects on pilot vision and performance. The purpose of this study is to investigate the relationship between visual impairment from natural sunlight and aviation accidents.

METHODS

The National Transportation Safety Board (NTSB) Aviation Accident/Incident Database was queried for terms related to glare from January 1, 1988, to December 31, 1998. Terms used in this search included, sun, glare, vision, blinded, and reflections. All reports annotated with one or more of these terms were reviewed to determine whether some form of glare from natural sunlight was considered a direct or contributing factor in the aviation accident. In this study, accidents and operational problems that did not involve the pilot-in-command of an air transport or general aviation aircraft were omitted from all search results. The remaining records were then organized by time of day, visual conditions, phase of flight, and type of operational error and analyzed.

RESULTS

For the study period, there were a total of 25,226 accidents in the NTSB Aviation Accident/Incident Database. Of these, there were 130 accidents in which direct or reflected glare from the sun was found to be a contributing factor in the event. Table 1 summarizes the ambient lighting (position of sun) and visual conditions (weather, atmospheric, or optical media) that were present during the mishaps.

Table 2 summarizes the accidents by phase of flight and the type of error that resulted from or was exacerbated by exposure to glare from natural sunlight.

Table 1. Aircraft accidents categorized by lighting and visual conditions.

LIGHTING	VISUAL CONDITIONS	FREQUENCY	TOTAL
Sunrise	Clear	6	**9**
	Smoke, Haze, Fog, or Dust	3	
Daytime	Clear	90	**106**
	Smoke, Haze, Fog, or Dust	9	
	Compromised Windscreen	7	
Sunset	Clear	15	**15**
TOTAL			**130**

Table 2. Aircraft accidents categorized by phase of flight and type of operational error.

PHASE OF FLIGHT	OPERATIONAL ERROR	FREQUENCY	TOTAL
Taxiing	Collision (object or terrain)	8	**8**
Takeoff/Departure	Collision (object or terrain)	6	**11**
	Loss of Control	3	
	Midair Collision	2	
In-Flight	Collision (object or terrain)	37	**50**
	Midair Collision	9	
	Loss of Power	4	
Approach/Landing	Collision (object or terrain)	46	**61**
	Loss of Control	7	
	Midair Collision	6	
	Loss of Power	2	
TOTAL			**130**

DISCUSSION

The results of the study confirm that glare from natural sunlight has caused visual impairment of pilots while operating aircraft and has contributed to aviation accidents. The majority of mishaps (85%), with glare mentioned as a contributing factor in the report narratives, occurred under optimal atmospheric and visual conditions (clear). In addition, most accidents occurred during daytime hours (82%), rather than in the early morning or evening hours (18%) when the sun was lower in the sky. It is important to note that there were several accidents in which other visual stressors were mentioned as contributing to the glare conditions. For example, atmospheric conditions (e.g., smoke, haze, fog, and dust) added to the pilot's difficulty in coping with disability glare (8.5%). Other confounding factors mentioned in accident reports included damaged or dirty windscreens (5.4%) and an inability of the pilot to view the cockpit instruments due to glare (2.3%).

Temporary visual impairment due to glare can have serious consequences for pilots during critical maneuvers performed at low altitude. The study results indicate that 55% (72/130) of the accidents involving glare occurred during the approach/landing and takeoff/departure phases of flight. The majority of these accidents (72%) involved collisions with objects or terrain. Approximately 75% of these collisions were due to under/overshooting the runway or failing to maintain alignment with the runway, suggesting an induced perceptual problem. Furthermore, of those who lost of control of the aircraft during the approach/landing or takeoff/departure phase of flight (14%), the accident reports described the pilots' inability to judge altitude and/or distance, which resulted in hard landings from flaring too early (or late), and unsuccessful attempts to abort landings or takeoffs, resulting in collisions with trees, power lines, utility/fence poles, or other structures near the runway. Two accidents (2.8%) on takeoff/departure and 6 (8.3%) during approach/landing were midair collisions that resulted from one or both pilots' failure to "see-and-avoid" the others' aircraft due to glare disability. Two (2.8%) pilots crashed on approach after losing power and being distracted by glare.

Thirty-seven of the 50 accidents (74%) categorized as "in-flight" involved collisions with objects or terrain. Of these, about 62% (23/37) involved aerial application of agricultural products (i.e., crop dusting). Although risky by nature, this activity is even more dangerous when the aircraft's windscreen becomes contaminated with agricultural spray products that exacerbate the effects of glare and further limits the pilot's outside view. Seven of the nine accidents (78%) that were listed as "midair collisions" were described as the pilot(s) failing to "see-and-avoid" the other aircraft due to glare from the sun. Four of the 50 "in-flight" accidents (8%) occurred when the aircraft lost power due to mechanical failure or fuel exhaustion, which forced the pilot to perform an emergency landing. The stress of the emergency landing, often in an unfamiliar location and complicated by glare, resulted in collisions with objects or the terrain.

Taxiing an aircraft around the airport can be made more difficult when glare is present. About 6% (8/130) of all accidents reviewed occurred while the aircraft was taxiing, either to takeoff or after landing. In several instances, the glare effects were exacerbated due to neglected windscreens (dirty, scratched, and pitted), which further scattered the sunlight.

As these accident reports illustrate, glare from natural sunlight can be visually debilitating and lead to operational errors that can result in mishaps. In some cases, use of appropriate sunglasses would have minimized the affects of glare on vision performance. However, when using sunglasses there should be a proper balance between visibility of objects inside and outside of the cockpit environment. Proper sunglasses include lenses that are free from distortions and imperfections, have adequate light transmissivity (approximately 15% overall light transmission), and do not alter color perception (e.g., neutral gray). Additionally, the use of larger lens sizes and wrap-around frame styles can prevent sunlight from entering peripherally and affecting the pilot's vision. Furthermore, the use of polaroid sunglasses should be discouraged, since they can reduce or effectively eliminate the visibility of instruments that incorporate anti-glare filters or can interfere with visibility through an aircraft windscreen due to striations in some laminated materials (39). Polaroid sunglasses can also mask the sparkle of light that reflects off shiny surfaces, such as another aircraft's wings, fuselage, or windscreen, which could reduce a pilot's reaction time in a "see-and-avoid" traffic situation.

Additional techniques that could help prevent operational errors resulting from glare exposure include:

- Enlist the assistance of a co-pilot or passenger to help read important instruments and/or printed flight documents so the pilot-in-command can focus his/her attention on overcoming glare conditions related to the exterior view;
- Deploy the aircraft's sun visor or use a brimmed hat to shield the pilot's eyes from exposure to glare;
- Avoid wearing light colored clothing that can create a reflection on the windscreen or instrument panel;
- Do not place light colored or reflective materials on the glareshield that can reflect light off the windscreen;

- Clean the windscreen thoroughly to prevent additional light scatter (Note: Preventive maintenance should include repair or replacement of the aircraft windscreen once it becomes scratched or pitted.);
- Be cautious about the use of medications that can be photosensitizing;
- Use navigation lights during the day while performing takeoff/departure and approach/landing maneuvers to allow other pilots to "see-and-avoid" your aircraft; and,
- Pilots with eye pathologies that may increase glare sensitivity (incipient cataract, age-related macular degeneration, etc.) should obtain appropriate sunglasses for use while flying.

In conclusion, glare from natural sunlight has contributed to aviation accidents. The use of appropriate ophthalmic lenses, personal protection devices, available human resources, proper aircraft maintenance, and other techniques to minimize the effects of disability glare discussed in this paper may have prevented some of the accidents identified in this study. Reviewing these events provides pilots, crewmembers, aviation medical examiners, and eyecare specialists with important facts and recommendations that can help prevent future operational mishaps associated with glare and improve aviation safety.

REFERENCES

1. Illuminating Engineering Society of North America. American National Standard Practice for Industrial Lighting. American National Standards Institute. 1983. ANSI/IES RP-7, 6, 38.

2. Abrahamsson M, and Sjostrand J. Impairment of contrast sensitivity function (CSF) as a measure of disability glare. Invest Ophthal Vis Sci. Jul 1986; 27(7):1131-6.

3. Storch RL, and Bodis-Wollner I. Overview of contrast sensitivity and neuro-ophthalmic disease. in Nadler MP, Miller D, Nadler DJ (eds.). Glare and Contrast Sensitivity for Clinicians. Springer-Verlag: New York, 1990; 85-112.

4. Regan D. Specific tests and specific blindnesses: Keys, locks and parallel processing. Optom Vis Sci. Jul 1991; 68(7):489-512.

5. IJspeert JK, de Waard PW, van den Berg TJ, and de Jong PT. The intraocular straylight function in 129 healthy volunteers: dependence on angle, age and pigmentation. Vision Res. 1990; 30(5):699-707.

6. Nakagawara VB, Montgomery RW, and Wood KJ. The applicability of commercial glare test devices in the aeromedical certification of pilot applicants. U.S. Department of Transportation/Federal Aviation Administration; 1994: FAA Report No. DOT/FAA/AM-94-15. Available from: National Technical Information Service, Springfield, VA 22161. Order #ADA 284232

7. van den Berg TJ, IJspeert JK, and de Waard PW. Dependence of intraocular stray light on pigmentation and light transmission through the ocular wall. Vision Res. 1991; 31(7-8): 1361-7.

8. Bichao IC, Yager D, and Meng J. Disability glare: effects of temporal characteristics of the glare source and of the visual-field location of the test stimulus. J Opt Soc Am A. Oct 1995; 12(10):2252-8.

9. Owsley C, Stalvey BT, Wells J, Sloane ME, and McGwin G Jr. Visual risk factors for crash involvement in older drivers with cataract. Arch Ophthalmol. Jun 2001; 119(6):881-7.

10. Mantyjarvi M, and Tuppurainen K. Cataract in traffic. Graefes Arch Clin Exp Ophthalmol. Apr 1999; 237(4):278-82.

11. Mainster MA, and Timberlake GT. Why HID headlights bother older drivers. Br J Ophthalmol. Jan 2003; 87(1):113-7.

12. Fong DS. Age-related macular degeneration: update for primary care. Am Family Physician. May 15, 2000; 61(10):3035-42.

13. Faubert J, and Overbury O. Binocular vision in older people with adventitious visual impairment: sometimes one eye is better than two. J Am Geriatrics Soc. Apr 2000; 48(4):375-80.

14. Richer S. A protocol for the evaluation and treatment of atrophic age-related macular degeneration. J Am Optom Assoc. Jan 1999; 70(1):13-23.

15. Lin S, Reiter K, Dreher AW, Frucht-Pery J, and Feldman ST. The effect of pterygia on contrast sensitivity and glare disability. Am J Ophthalmol. Apr 1989; 107(4):407-10.

16. Titiyal JS, Das A, Dada VK, Tandon R, Ray M, and Vajpayee RB. Visual performance of rigid gas permeable contact lenses in patients with corneal opacity. CLAO J. Jul 2001; 27(3):163-5.

17. Jewelewicz DA, Evans R, Chen R, Trokel S, and Florakis GJ. Evaluation of night vision disturbances in contact lens wearers. CLAO J. Apr 1998; 24(2): 107-10.

18. Miller D, and Lazenby GW. Glare sensitivity in corrected aphakes. Ophthalmic Surg. Dec 1977; 8(6):54-7.

19. Harper RA, and Halliday BL. Glare and contrast sensitivity in contact lens corrected aphakia, epikeratophakia and pseudophakia. Eye. 1989; 3(Pt5): 562-70.

20. LeClaire J, Nadler MP, Weiss S, and Miller D. A new glare tester for clinical testing: results comparing normal subjects and variously corrected aphakic patients. Arch Ophthalmol. Jan 1982; 100(1):153-8.

21. Alio JL, de la Hoz F, Perez-Santonja JJ, Ruiz-Moreno JM, and Quesada JA. Phakic anterior chamber lenses for the correction of myopia: a 7-year cumulative analysis of complications in 263 cases. Ophthalmol. Mar 1999; 106(3):458-66.

22. Dick HB, Krummenauer F, Schwenn O, Krist R, and Pfeiffer N. Objective and subjective evaluation of photic phenomena after monofocal and multifocal intraocular lens implantation. Ophthalmol. Oct 1999; 106(10):1878-86.

23. Nadler DJ, Jaffe NS, Clayman HM, Jaffe MS, and Luscombe SM. Glare disability in eyes with intraocular lenses. Am J Ophthalmol. Jan 1984; 97(1):43-7.

24. Tan JCH, Spalton DJ, and Arden GB. Comparison of methods to assess visual impairment from glare and light scattering with posterior capsule opacification. J Cataract Refract Surg. Dec 1998; 24(12): 1626-1631.

25. Claesson M, Klaren L, Beckman C, and Sjostrand J. Glare and contrast sensitivity before and after Nd:YAG laser capsulotomy. Acta Ophthalmol (Copenh). Feb 1994; 72(1):27-32

26. Applegate RA, Trick LR, Meade DL, and Hartstein J. Radial keratotomy increases the effects of disability glare: initial results. Ann Ophthalmol. Aug 1987; 19(8):293-7.

27. Ghaith AA, Daniel J, Stulting RD, Thompson KP, and Lynn M. Contrast sensitivity and glare disability after radial keratotomy and photorefractive keratectomy. Arch Ophthalmol. Jan 1998; 116(1): 12-18.

28. Gartry DS, Kerr-Muir MG, and Marshall J. Excimer laser photorefractive keratectomy: 18 month follow-up. Arch Ophthalmol. Aug 1992; 99(8): 1209-19.

29. Diamond S. Excimer laser photorefractive keratectomy (PRK) for myopia--present status: aerospace considerations. Aviat Space Environ Med. Jul 1995; 66(7):690-3.

30. Ivan DJ, Tredic TJ, Perez-Becerra J, Dennis R, Burroughs JR, and Taboada J. Photorefractive keratectomy (PRK) in the military aviator: an aeromedical perspective. Aviat Space Environ Med. Aug 1996; 67(8):77-6.

31. el Danasoury MA. Prospective bilateral study of night glare after laser in situ keratomileusis with single zone and transition zone ablation. J Refract Surg. Sep-Oct 1998; 14(5):512-516.

32. Novack GD. Ocular toxicology. Curr Opin Ophthalmol. Dec 1994; 5(6):110-4.

33. Mathison IW, and Haas KL. Drug photosensitivity. I. Light- and photo-sensitivities observed during oral contraceptive therapy. A review. Obstet Gynecol Surv. Apr 1970; 25(4):389-401.

34. Caffery BE, and Josephson JE. Ocular side effects of isotretinoin therapy. J Am Optom Assoc. Mar 1988; 59(3):221-4.

35. Adams AJ, and Brown B. Alcohol prolongs time course of glare recovery. Nature. Oct 1975; 257(5526):481-3.

36. Adams AJ, Brown B, Haegerstrom-Portnoy G, Flom MC, and Jones RT. Marijuana, alcohol, and combined drug effects on the time course of glare recovery. Psychopharmacology (Berl). Jan 31, 1978; 56(1):81-6.

37. Aerospace medicine: flight surgeon's guide. Washington, D.C.: Department of the Air Force. 1968. Air Force Pamphlet No. 161-18.

38. Curtis JL. Visual problems of high altitude flight. in: Mercier A. (ed). Visual Problems in Aviation Medicine. The MacMillan Company:New York City. 1962; 39-44.

39. Swearingen JJ, and Johnson GR. Strain patterns in aircraft windshield and visibility through polaroid sun glasses. 1948. Oklahoma City, OK: United States Civil Aeronautic Administration, Aeronautical Center, Civil Aviation Medical Research laboratories. Report No. AC 8500-1.